



## AUSTRALIAN RESOURCES AND ENVIRONMENTAL ASSESSMENT (AREA) MODEL

A study by the Department of Science and the Environment in consultation with Commonwealth departments and agencies

### THE QUANTIFICATION OF ENVIRONMENTAL STRESS USING THE SARUM/AREAM GLOBAL MODEL

by

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and

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*The views expressed in this paper do  
not necessarily reflect the opinions  
of the Department of Science and the  
Environment, nor of the  
Australian Government.*

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*SARUM is a world econometric model developed by the System Analysis Research Unit of the UK's Department of the Environment, in which prices do not adjust to equilibrate supply and demand in each period, but rather recognise the many factors that inhibit instantaneous clearing of markets. The world can be regionalised into twelve regions and a number of industrial and agricultural activities.*



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*AREAM is the Australian version of SARUM for the analysis of Australian Resources and Environmental Assessment. The project was formulated in the light of a need to assess the impact of world change on the development of the Australian environment and its natural resources. In order to be able to look at environmental factors, SARUM is extended by the addition of an environment sector and the demographic sector is endogenised.*

# ABSTRACT

In what is a first attempt to incorporate environmental impacts into a global macro-economic model, this paper shows how a post processing environment sector has been added to the SARUM/AREAM model. Again as a first look at environmental stresses caused by economic activities, the paper concentrates on solid wastes particularly from mining activities, as these are seen as producing the largest solid waste problems in the future. This analysis is carried out within various trading policies that Australia may follow and the consequential trade off between standard of living and level of environment stress that may result from such policies. The paper does show that environment impacts are tied to how Australia will react to global demands for resources and that assessment of resources and environment issues must take into consideration global interdependence.

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1. INTRODUCTION

This paper discusses how a large-scale economic model can be used to assess environmental stresses. The model used for these studies is SARUM, the global model developed by the Systems Analysis Research Unit of the Department of the Environment in the U.K. SARUM has been described in detail elsewhere, (Department of the Environment, Department of Transport 1977), (Parker and Raftery 1978), (Wagstaff 1979), and was also presented to the 4th IIASA Global Modelling Conference (IIASA, 1978). It has most recently been used by the OECD Interfutures project to investigate relations between developed and less developed countries (OECD 1979). SARUM is also currently being used by the Commission for the Future in New Zealand to investigate possible future roles for New Zealand in the world. These uses of the model are only concerned with economic and

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\* On secondment from the Department of the Environment,

London, U.K. The views expressed in this paper do not necessarily reflect the opinions of the Department of

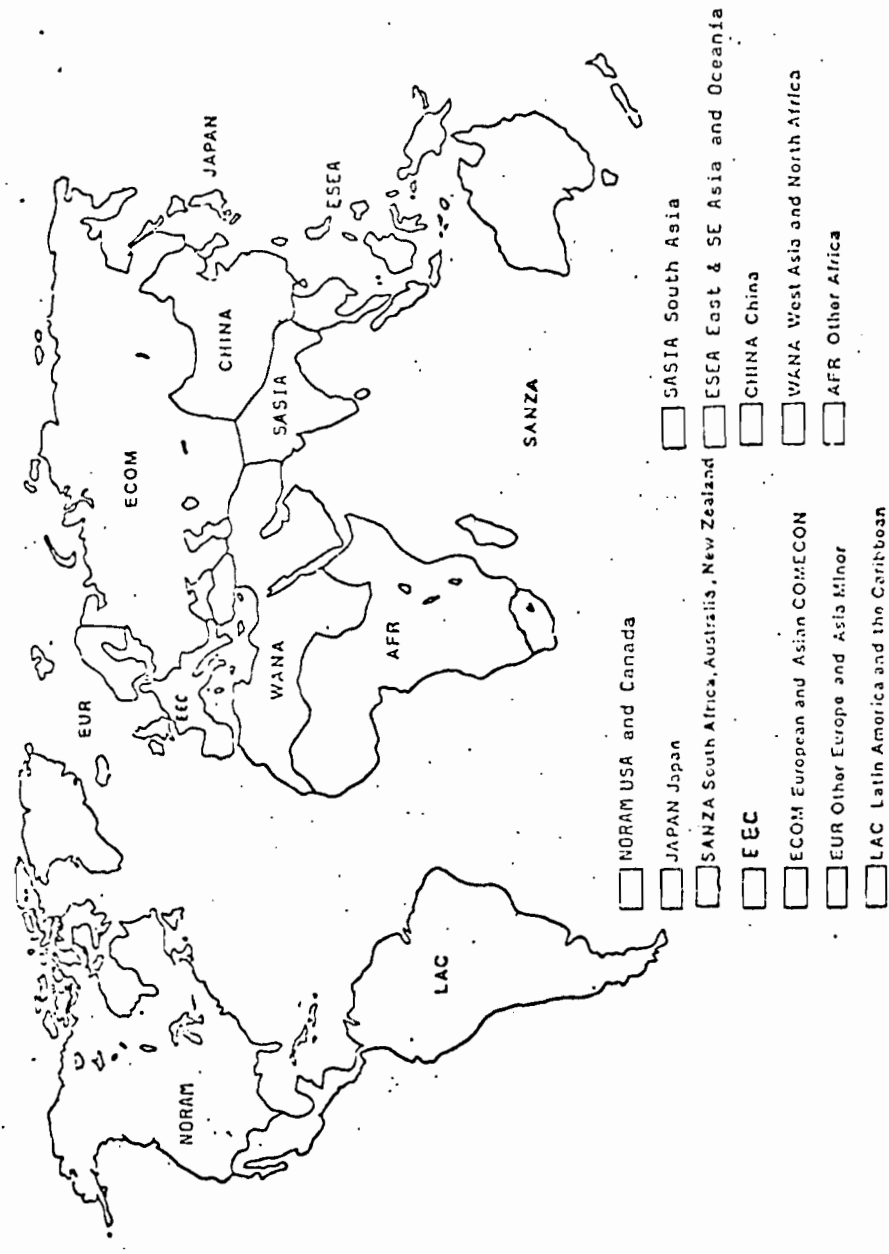
Science and the Environment, nor of the Australian Government.

natural-resource aspects of possible world futures; the extensions which will incorporate an environmental sub-model are being carried out by the Department of Science and the Environment in Canberra as part of their Australian Resources and Environmental Assessment (AREA) Project.

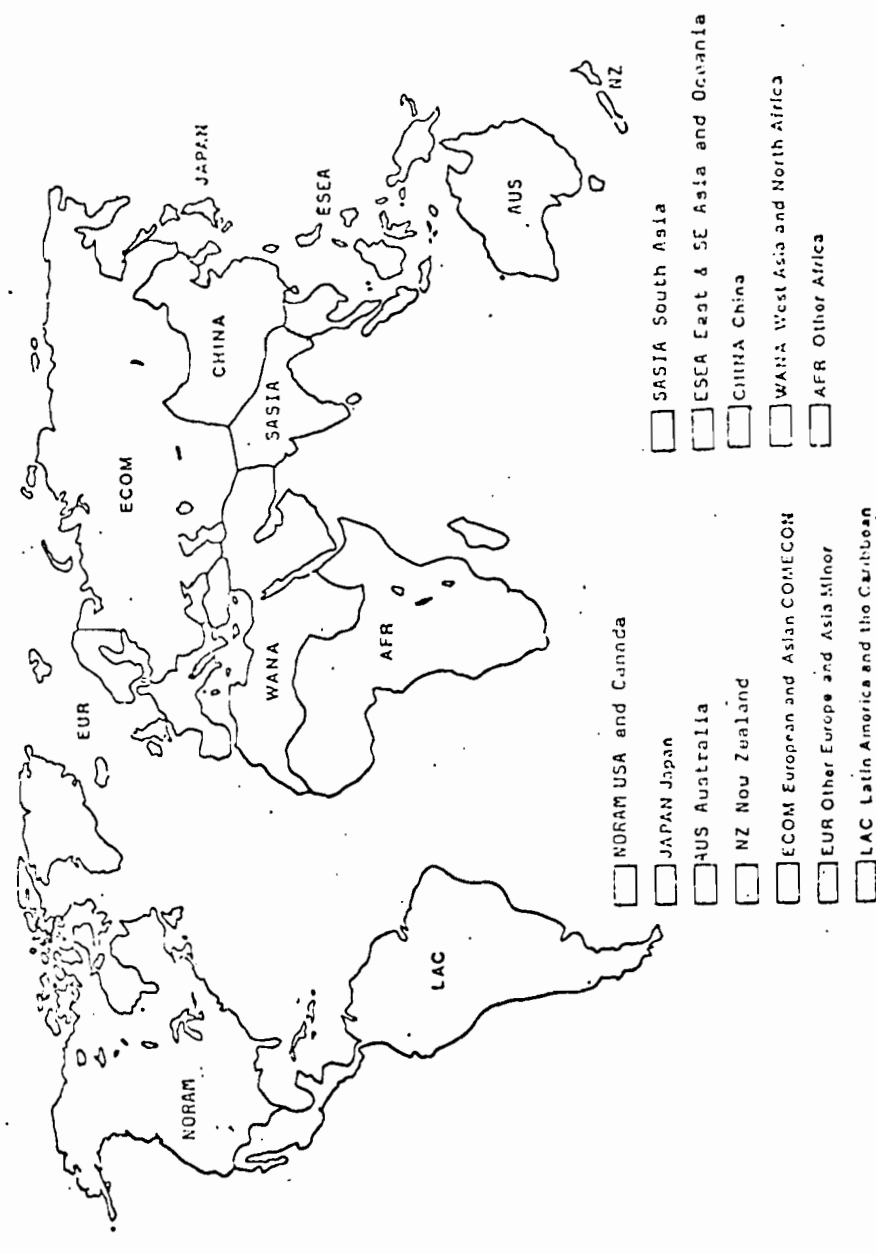
AREA has taken the SARU regionalisation of the world used for the Interfutures project and within the 12 regions has two new regions for Australia and New Zealand (EEC and Western Europe have been grouped as one region and South Africa grouped into Africa). See Figure 1. Two additions to the SARU model that will be made are population and the environment sub-models, the latter being the subject of this paper. For population it is hoped to replace the present exogenous UN projections with an endogenous demograph mechanism for the Australian and New Zealand regions based on modelling work already carried out in Australia. Migration will also be modelled using a mechanism similar to that developed for trade - a migration bias matrix. Along with the environment sub-model, the impact on the Australian environment and its natural resources, of economic conditions and demographic change world-wide, will be monitored and assessed. The AREA Project itself is in fact a pilot study to measure the utility of using models of this nature for prospective analysis within the government policy framework.

FIGURE 1

## (A) REGIONS FOR SARUM PROJECTIONS



## (B) REGIONS FOR AREAM PROJECTIONS



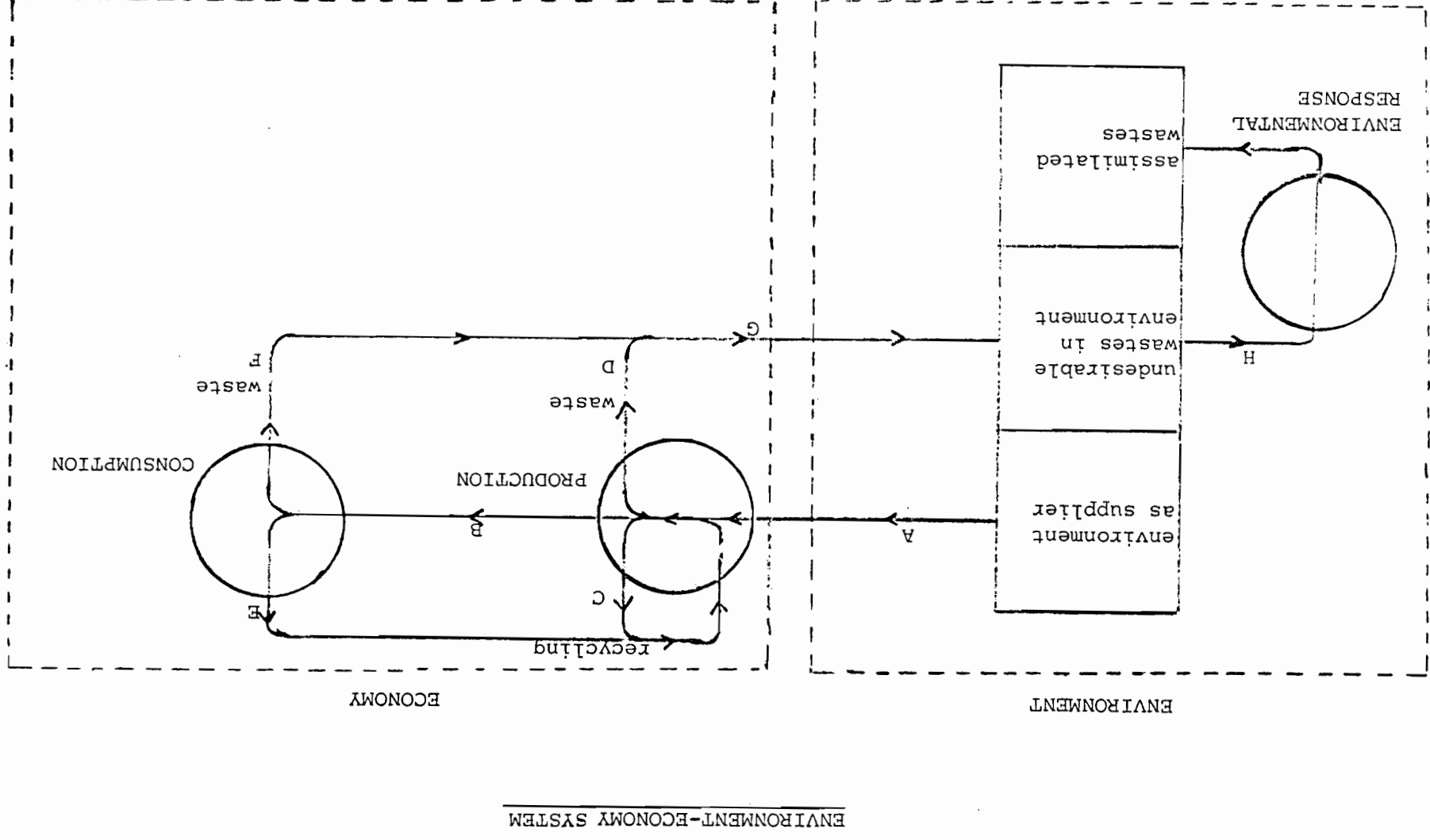
## 2. THE ENVIRONMENT SUB-MODEL

The study of the inter-relationships between the economy and the environment covers such a wide range that it is impossible for one model to provide a comprehensive coverage. It is always essential when using a model to tackle problems to which it is well suited; different areas of study will require different approaches. A first useful step in narrowing down the study area is to distinguish between environmental stress and environmental impact, or response. Stress relates to human activity which affects the environment, whereas the consequential effects on the environment and the ways in which it responds are referred to by the term environmental impact. For example, the emission of sulphur dioxide from a coal-burning power station is an environmental stress, but the effect on river fish of the resulting sulphuric acid in the rain is an impact. Ultimately, interest will focus on the response of the environment; it is the deleterious impacts which are to be avoided, or borne for the sake of some greater advantage. Stresses which are part of an ecological equilibrium do not usually give rise to great concern; for example, the activities of hunter-gatherer societies. This classification of stress and response is used by the Australian Environmental Statistics Project (AESOP) (Friend 1978).

The analysis of environmental impact involves many branches of science such as meteorology, ecology, chemistry and medicine. However vital those studies are, they cannot proceed without knowing the size and location of the stresses. Since most stresses are intimately bound up with economic activity, any assessment of future environmental stresses requires quantitative economic projections. SARUM is a model which provides quantitative projections of many economic variables and so is a suitable tool for providing estimates of future stress levels. It should be emphasised here that long-term economic models cannot provide forecasts; the vagaries of world politics can confound any prediction. Therefore such models can only be used for providing conditional forecasts, answering "What if?" questions. The set of assumptions needed to perform a model simulation is usually termed a scenario. Several scenarios are discussed in the next section where it will be seen that very different futures can arise from different assumptions. The value of the model exercises lies in the help they give to understanding a complex system where many interactions are involved.

Many important stresses are associated with direct release of substances or energy into the environment, for instance solid wastes from mining and waste heat from power stations. The laws of conservation of matter and energy (ignoring relativistic effects) allow a self-consistent material-energy balance approach to be used. (Pearce 1976),

(Victor 1972). Figure 2 shows the flows of material or energy in the environment-economy system. It can be seen that there is a flow of raw materials from the environment, acting in the role of supplier, (e.g. minerals extraction) which then goes into the production sector where it is transformed into goods for consumption, B, and waste is either discharged, D, or recycled C. The flow to consumption is eventually either discarded, F, or recycled E. There is obviously some build-up in these sectors associated with capital equipment in the production process and consumer durables. However, it can reasonably be assumed that all human artefacts have a finite life and are eventually discarded or recycled. The total waste flow, G, returns to the environment. Some of these wastes, H, can be assimilated, at varying speeds, by the environment. As mentioned before, the response of the environment to stresses is a complicated topic requiring specialist knowledge. Therefore the first step in the present study is to restrict our analysis to the workings of the economy and its direct connections with the environment. Using the notation of Figure 2 this implies that assessment of environmental effects will be restricted to flows A and G, the extraction of material and energy from the environment, and their ultimate disposal as waste. However, this does not preclude the study of impacts at some future stage.





The stresses which are to be investigated must depend on economic variables available in the model. In many cases a simple coefficient will suffice, for example the number of tonnes of sulphur dioxide released for every tonne of coal burnt. However, more complicated relationships could be used which take into account such things as the increase in mine wastes per tonne of metal content as ore grades decline. Assumptions can also be made about how these coefficients may change over time, perhaps as a result of greater pollution controls or an increase in recycling. Such assumptions will form part of the scenario and are an essential component of any analysis and discussion of the final results. Finally, apart from stresses which are a function of economic variables, some model outputs can be considered as environmental stress indicators without any further transformation. Obvious examples are connected with agriculture where there is concern about such problems as the acceleration of soil erosion due to more intensive farming, the run-off of fertilizers into water courses and the increase in salination caused by irrigation. The yield per hectare, and the total fertilizer and irrigation water consumed are available directly from the model and would be suitable indicators for the problems just mentioned.

### 3. RESULTS

A reference simulation was carried out against which several other variant scenarios could be compared, all of them using the regional disaggregation of Figure 1(B). Such an approach is useful for drawing inferences about what are the important factors in the problems under consideration. The reference experiment uses the low growth rates of Interfutures Scenario B2, approximately based on extrapolation of late 1970's trends. However, the trade assumptions are different in that the biases (Parker 1977) are assumed constant rather than falling. The biases represent the factor by which any particular trade flow (e.g. food exports from Australia to Western Europe) is less than that which would be expected in a perfect, free-trade world, having made due allowance for price differences.

The stresses we shall examine relate to the disposal of solid waste in the environment. These discharges form a self-contained set on which data are readily available. The source we have used is Beretka (1978). One point worth drawing attention to about the disposal of solid wastes in Australia is illustrated in Figure 3. The great majority of the population live near the coast, but as can be seen, many of the stresses associated with mining and industry are also situated in this area. The stresses and the model variables they relate to are shown in Table 1. All are related by simple coefficients apart from domestic waste which is a linear weighted function of the three components.

FIGURE 3  
DISTRIBUTION OF MAJOR WASTES AND BY-PRODUCTS

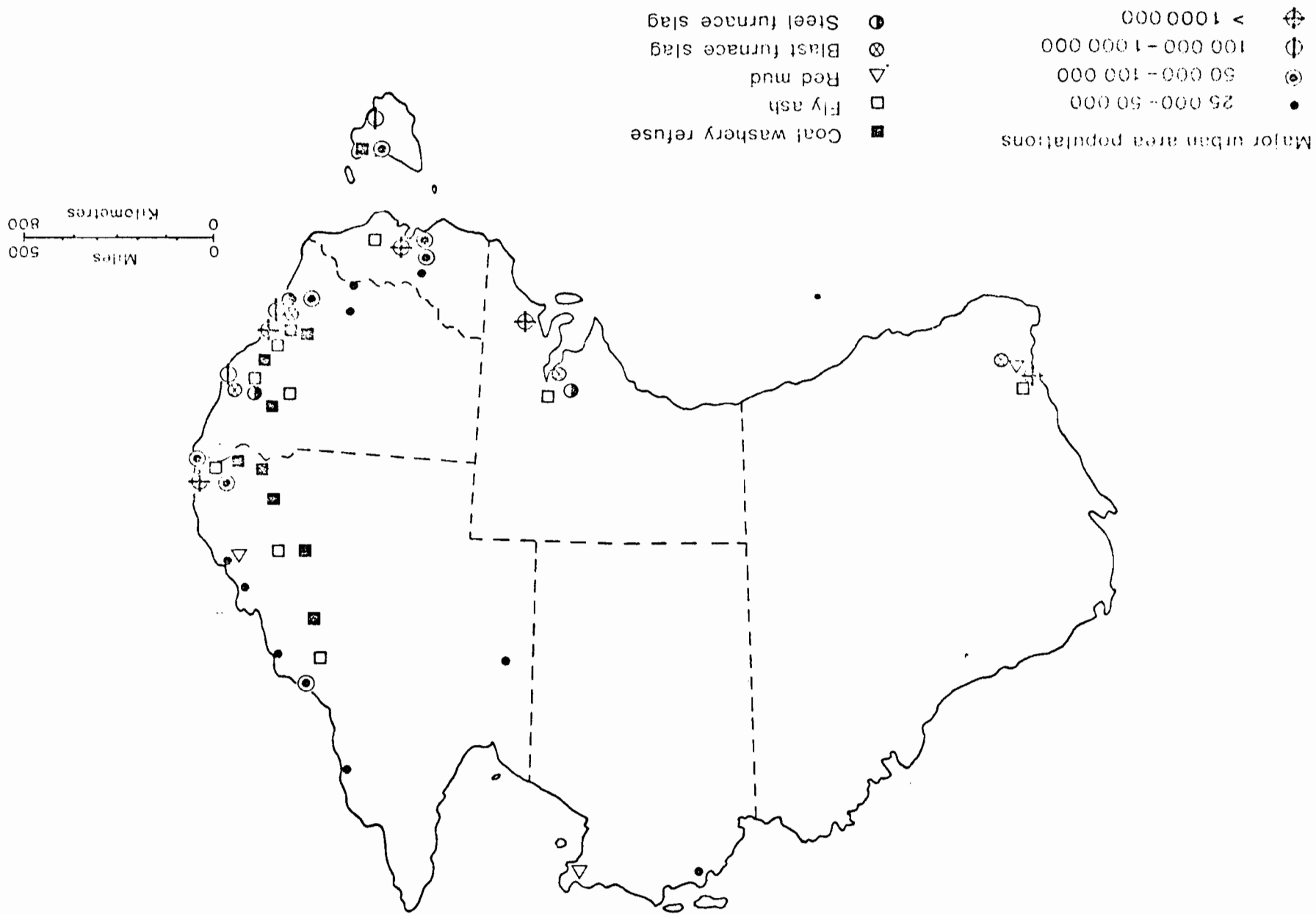


TABLE 1  
STRESSES AND THE ACTIVITIES CAUSING THEM

STRESS	ACTIVITY IN ECONOMIC MODEL	
1. Waste from coal washeries	Production of energy	Production of energy
2. Fly-ash from power stations	Consumption of energy	Consumption of energy
3. Mine tailings	Production of minerals	Production of minerals
4. Red mud from bauxite refining	Production of minerals	Production of minerals
5. Slag from ferrous metal production	Manufacturing production	Manufacturing production
6. Slag from non-ferrous metal production	Manufacturing production	Manufacturing production
7. Domestic waste	Final consumption of manufactures, natural products and food.	Final consumption of manufactures, natural products and food.

Figures 4 and 5 show the release of solid wastes into the environment associated with the reference experiment. All coefficients have been set so as to give the correct values for waste production in 1975. The coefficients have been assumed constant, which implies an unchanging fraction recycled. The most striking result is the increase in the discharge of coal wastes. This is associated with the growth in Australia's exports of energy, mainly to Japan. The growth rate of energy production between 1970 and 2020 is  $3.8\% \text{ yr}^{-1}$  compared with an average for the whole economy of  $2.5\% \text{ yr}^{-1}$ . The growth rate in minerals production over the same period is  $2.8\% \text{ yr}^{-1}$  which, though not so great, still leads to very large amounts of red mud to be disposed of. According to Beretka (op cit) there is no economic way of reusing either of these two major waste products. Given the level of energy and minerals production, the figures for wastes are likely to be underestimates because of depletion. As more and more coal is extracted it is likely that thinner seams and lower quality coal will have to be mined, which will result in more waste per tonne of coal.

One possible economic future for Australia would be to pursue a policy of close economic links with its neighbours in the West Pacific. An experiment was performed in which the trade biases between Australia, New Zealand, Japan and East and South East Asia fell from 1980 onwards towards the lowest values observed in the world at rates

FIGURE 4

WASTES FROM COAL WASHERIES REFERENCE EXPERIMENT

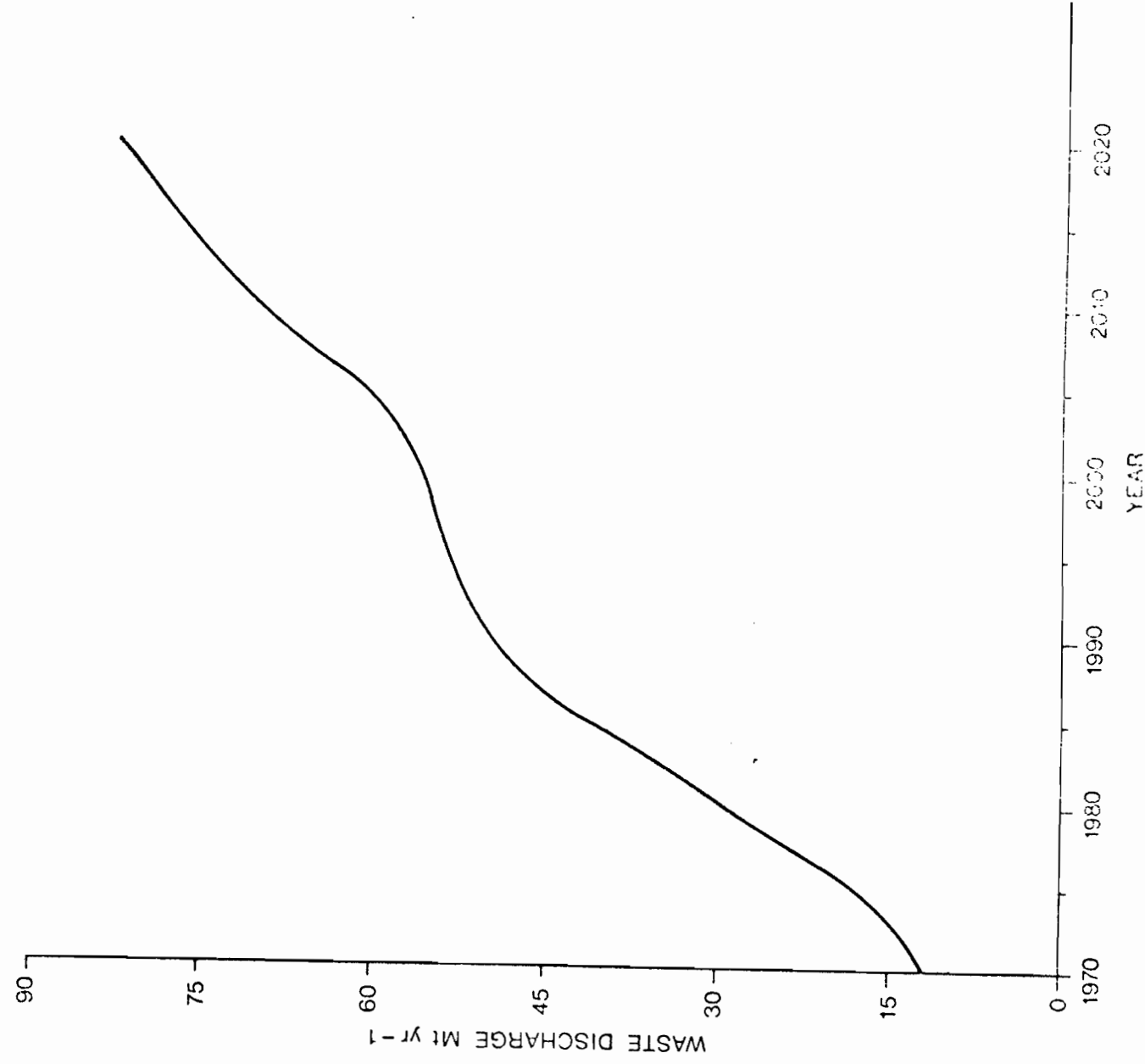
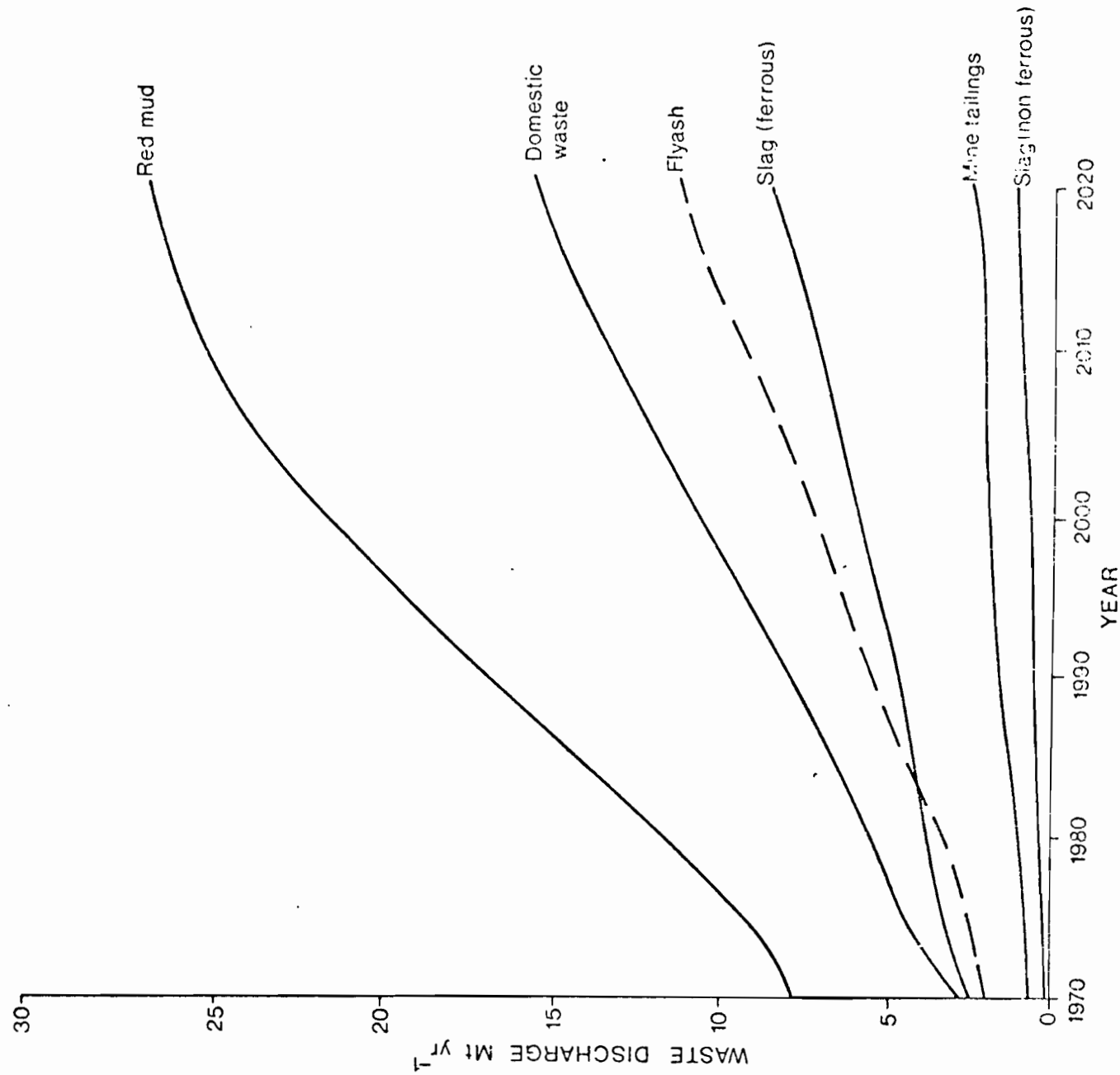


FIGURE 5  
SOLID WASTES, VARIOUS SOURCES, REFERENCE EXPERIMENT



commensurate with those observed in the European Economic Community. The general picture that emerges is that Australia moves even more in the direction of being an exporter of primary products and an importer of manufactures. The effects on the discards of coal waste and red mud are shown in Figures 6 and 7. It can be seen that as a consequence of greater exports, the trade liberalisation leads to an increase in the production of energy and minerals in Australia, with a consequent rise in the quantities of coal and mineral wastes. The sudden changes which occur in the coal-waste curve arise from the fact that with freer trade consumers can switch rapidly from one supplier to another as differential depletion affects relative prices.

The liberalised trade scenario benefits Australia in gross consumption per person (17% higher in 2020 than the reference experiment), but at the expense of greater environmental degradation associated with mining and minerals extraction. However, because they import many more manufactures, environmental stresses associated with industrial production are reduced. For example, in 2020 the slag from ferrous metals discarded drops from 8.2 Mtyr<sup>-1</sup> to 4.8Mtyr<sup>-1</sup>.

The idea of Australia becoming a quarry and mine pit for other countries may not be attractive to its citizens. Therefore a scenario was postulated in which both exports of energy and minerals and imports of manufactures were reduced from 1980 onwards. The biases were changed

FIGURE 6  
WASTES FROM COAL WASHERIES

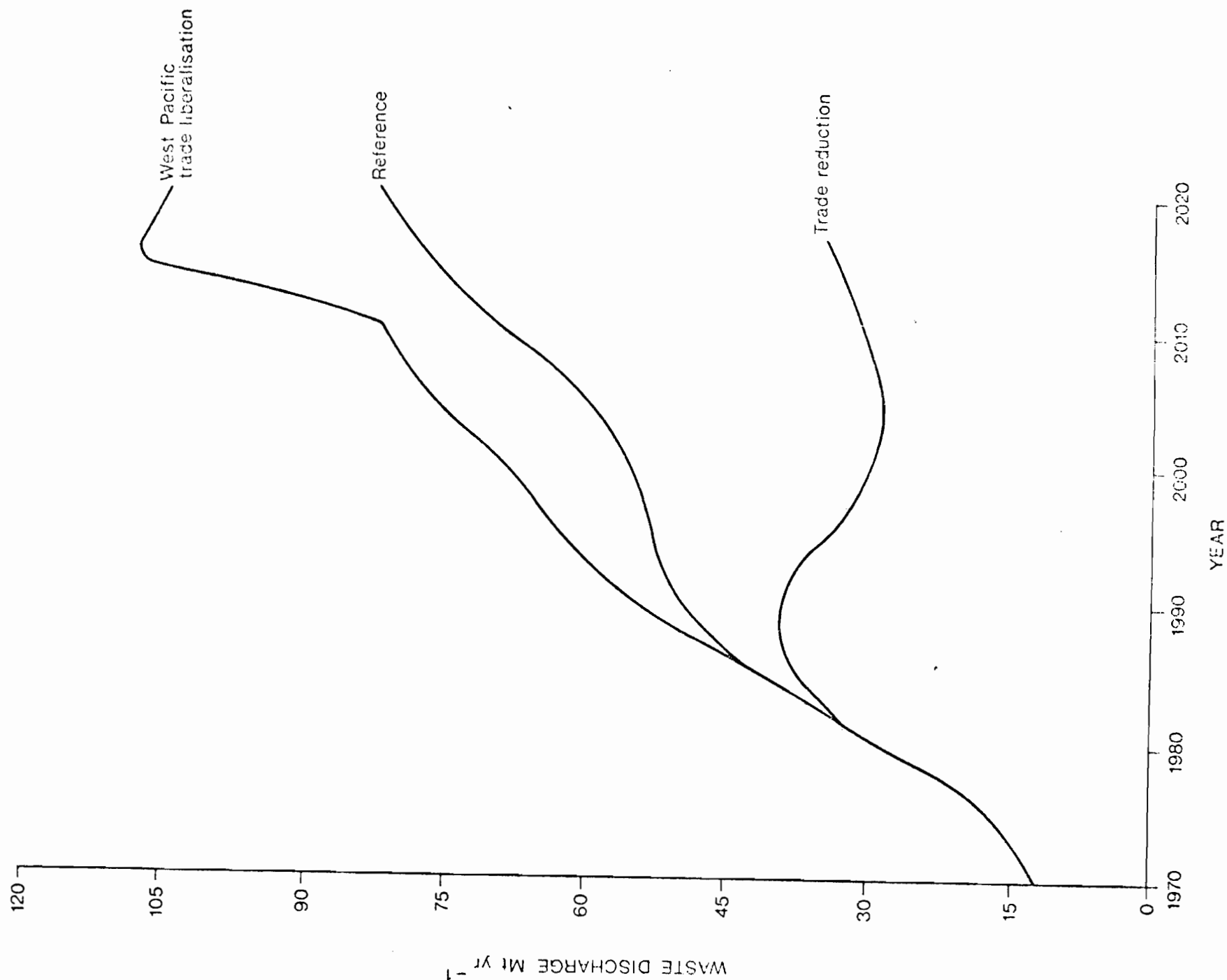
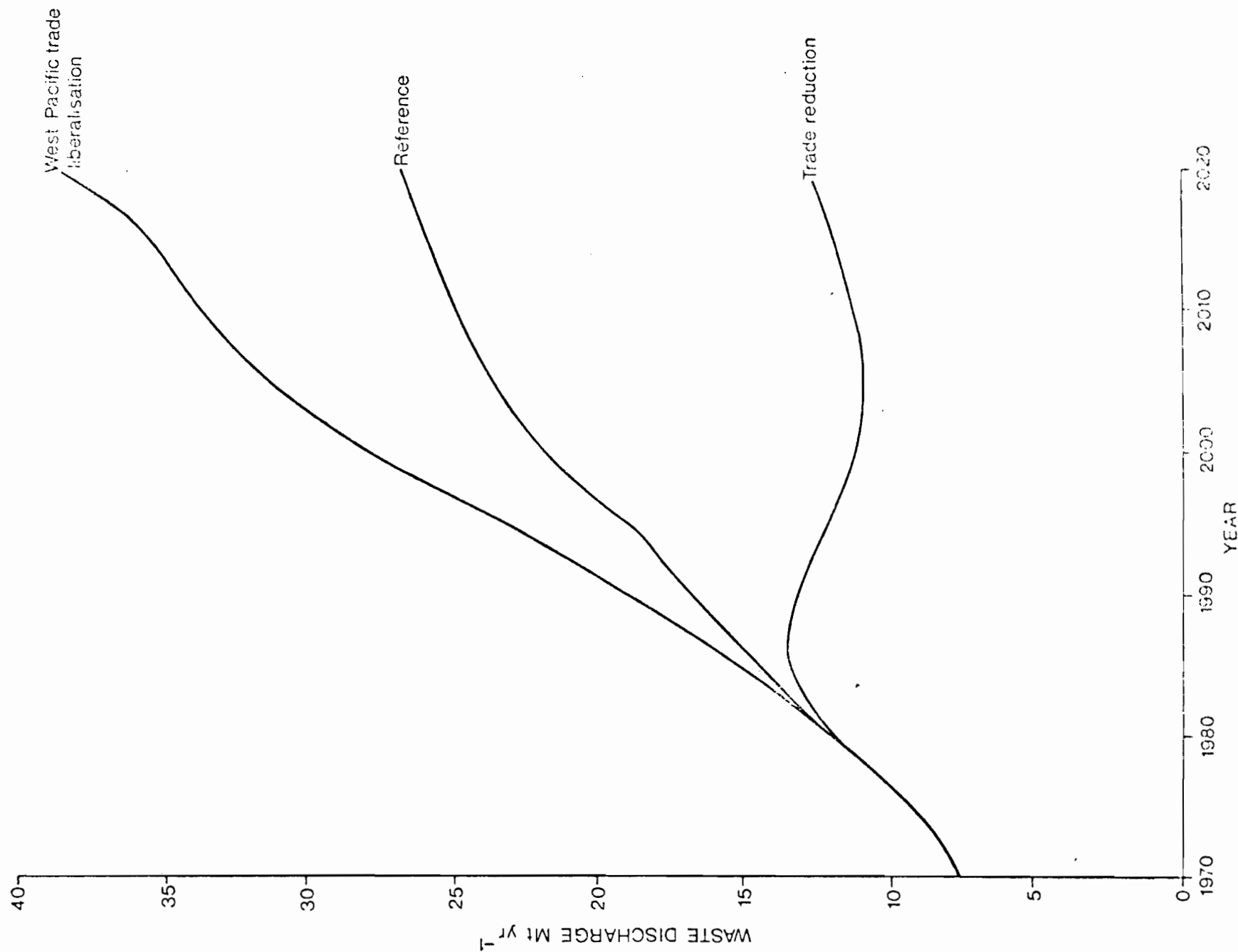


FIGURE 7  
RED MUD WASTES



at the same rate as for the liberalisation experiment, but in the opposite direction. This is feasible because these trade flows, in money terms, approximately cancel each other out. Figures 6 and 7 show the environmental consequences. The reductions in stress are very great indeed as exports are restricted. However, from 2005 onwards, once exports are very small, Australia's own rising requirements lead to an upward turn in the stress levels. However, a price has to be paid for this environmental improvement. Because there is import substitution of manufactures, stresses associated with industry increase. Compared with the reference, the discards of slag from ferrous metals are 18% higher by the end of the experiment. The most important adverse effect is a fall in standard of living of almost 10%. The trade-off curve is shown in Figure 8. This shows the fall in consumption per person against the fall per person in discards of coal waste. It is interesting to note the increasing marginal cost; as time goes by a given reduction in stress implies a greater and greater reduction in consumption.

As mentioned earlier, the model outputs can be used directly as environmental indicators. Some results from the three scenarios discussed are shown in Figures 9, 10 and 11. The rise seen in each indicator towards the end of the simulations is due to increased exports of food to East and South East Asia. This region's increased

FIGURE 8  
COAL WASTE/CONSUMPTION TRADE OFF

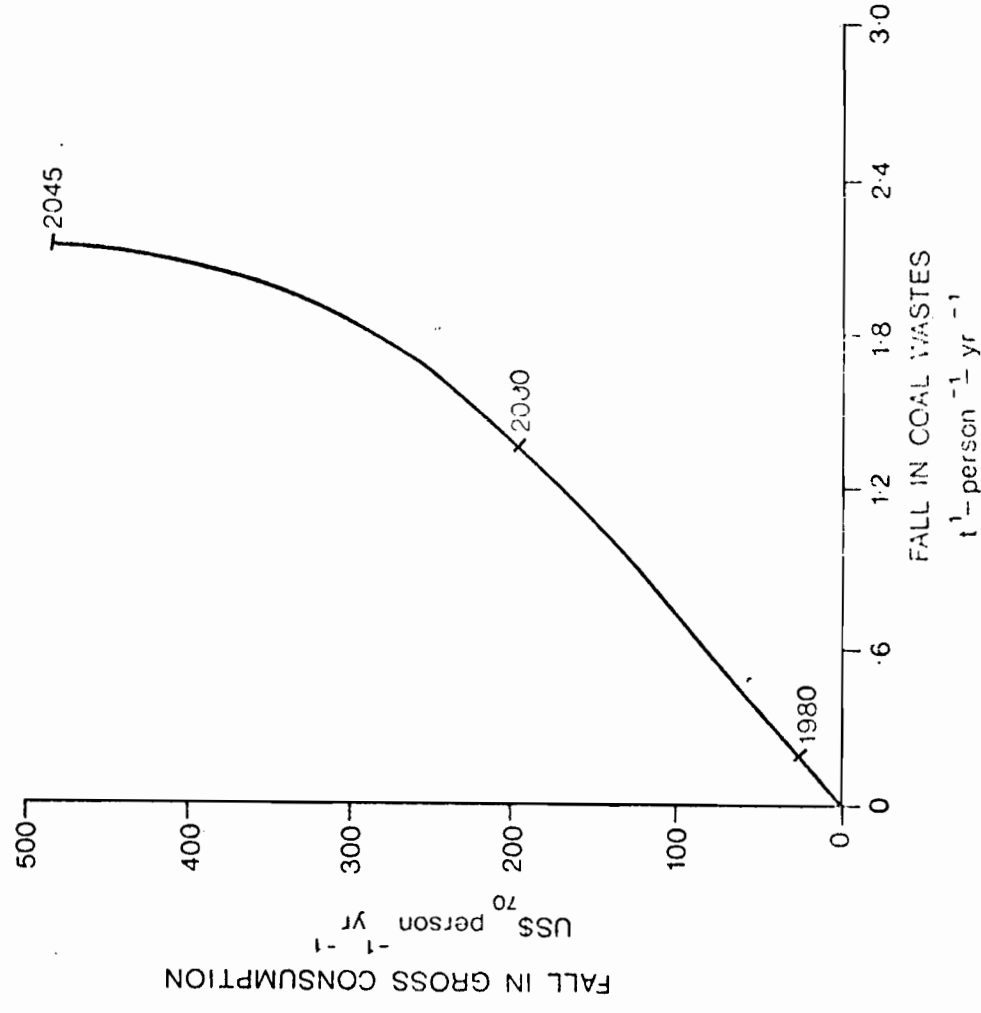


FIGURE 9  
YIELD PER HECTARE (CEREAL EQUIVALENT)

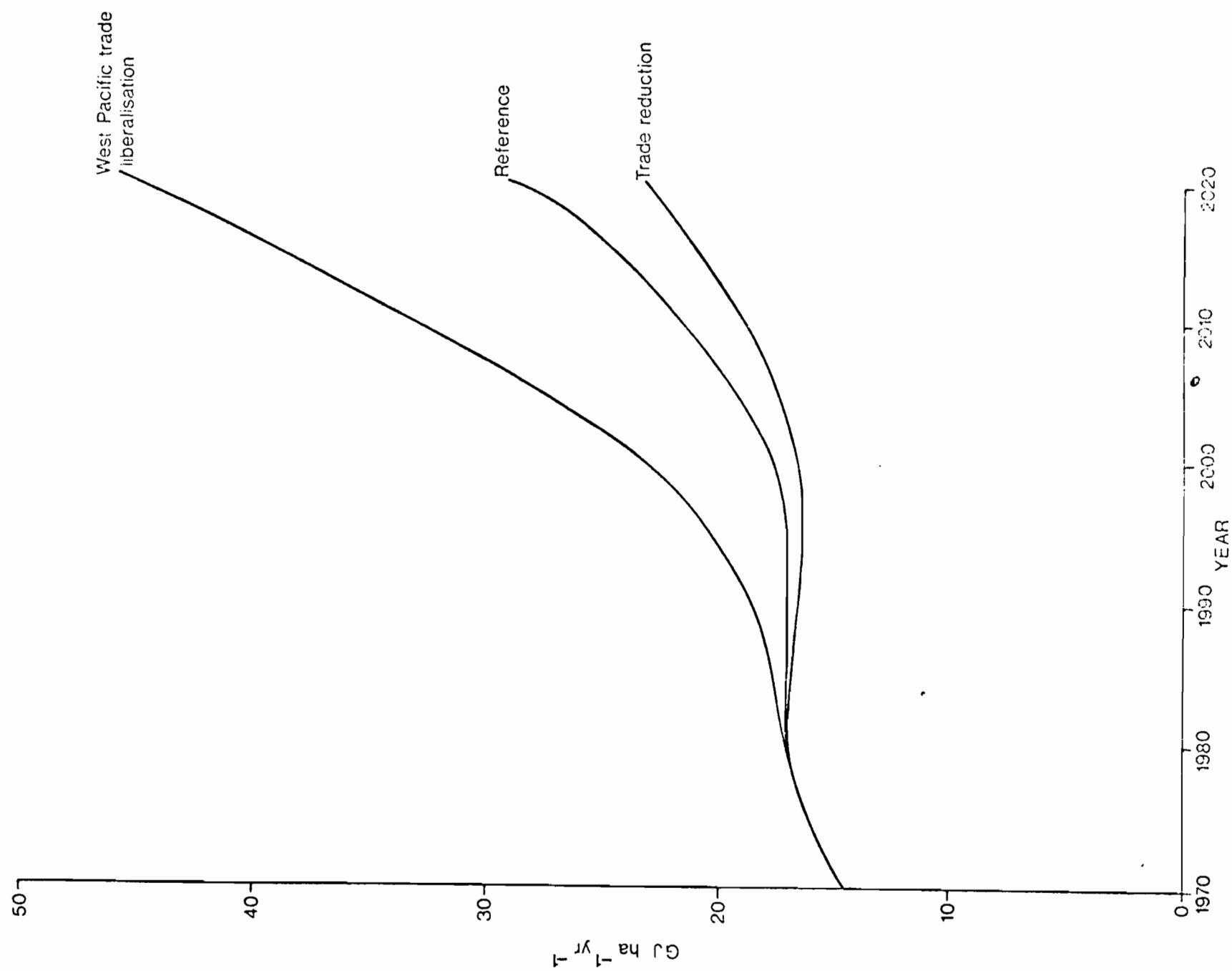


FIGURE 10  
TOTAL FERTILIZER USE

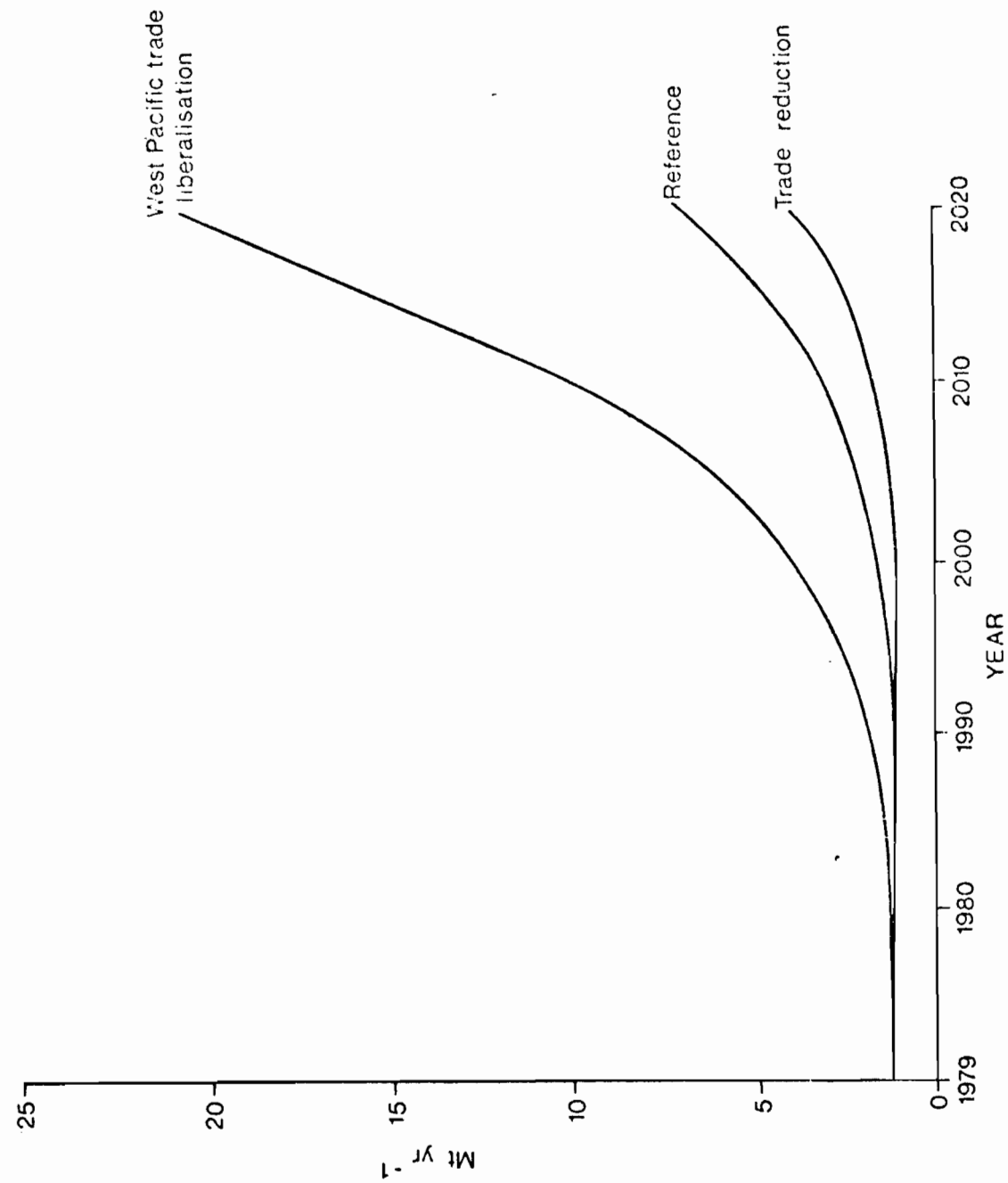
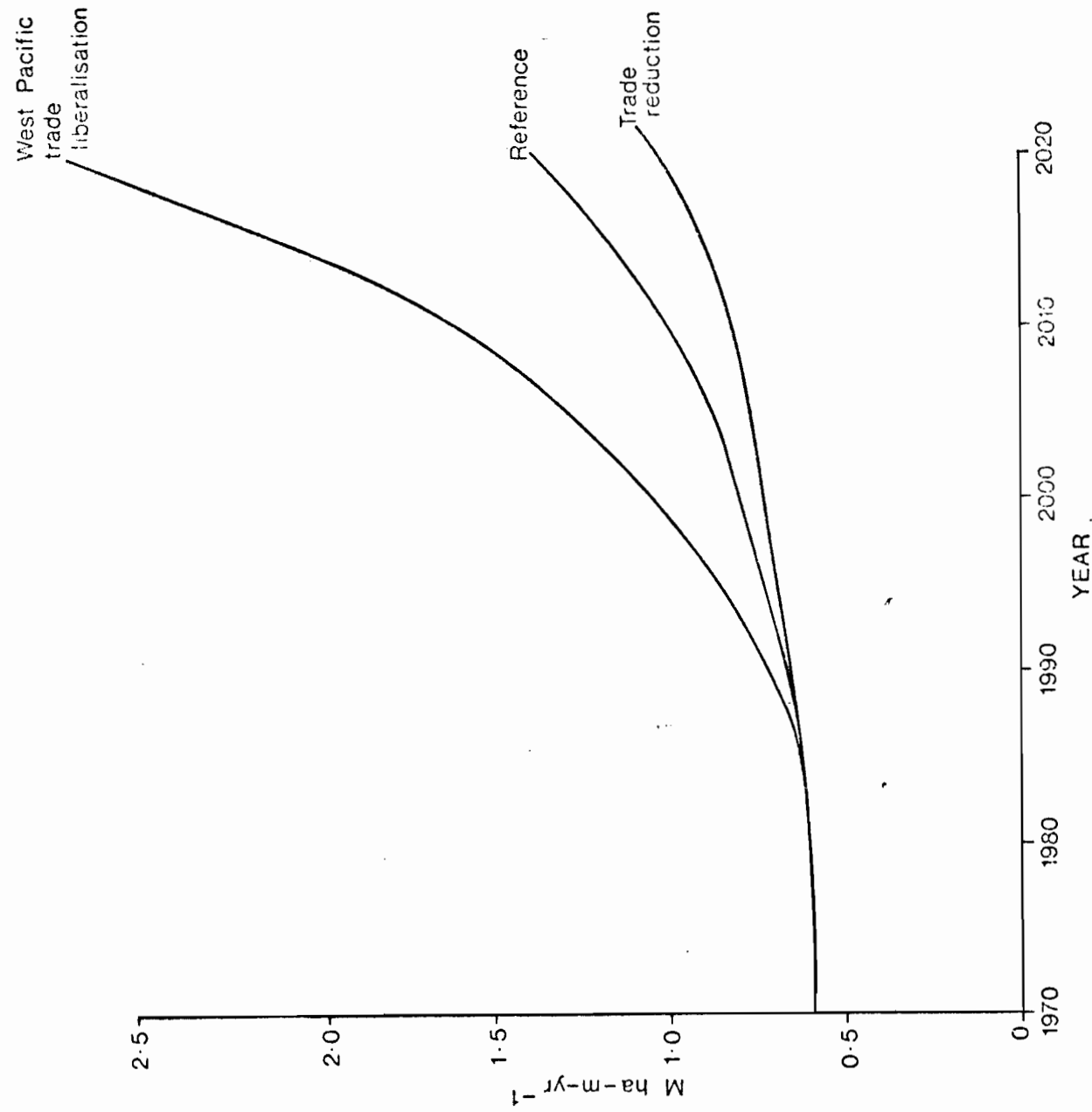


FIGURE 11  
TOTAL USE OF IRRIGATION WATER



imports are caused by its rising standard of living and growing population which increase the demand for food, but since their potential for increasing production is severely limited they must import. The liberalisation of trade in the Western Pacific greatly enhances this trend and the environmental impacts on the Australian countryside could be very considerable; the total fertilizer consumption in 2020 is triple what it is in the reference experiment.

Only a limited number of results have been presented here, but they indicate the scope of possible studies of the environmental consequences of economic actions which can be carried out using a model such as SARUM. The results should only be taken as broad indicators of what might happen to the environment. The disaggregation of the Australian economy into only eleven sectors is too coarse to capture many affects precisely. Also the assumption that the coefficients are constant is obviously open to doubt; new techniques and recycling could reduce them. However, waste is inextricably associated with mining and quarrying and has little potential for recycling as, say, building materials (Beretka, op cit). Therefore it seems inevitable that if Australia continues on the path of being a large exporter of coal and minerals, very large quantities of solid waste will have to be disposed of in the environment.



#### 4. FURTHER DEVELOPMENTS OF THE ENVIRONMENT SUB-MODEL

The preliminary stage of the SARUM/AREAM study has been described, and there are several extensions which are actively being considered. One direction for further work has already been described; that is the analysis of environmental impact. The way the assimilative capacity of the environment is reduced by further environmental stresses can be very important, and the work of Torres and Pearce (1979) in this field could be very useful.

Many other important improvements involve facing the problems of evaluating environmental damage in monetary terms. Many approaches have been made based on cost-benefit methods in which direct attempts are made to evaluate environmental damage (Kolm 1972), (Coomber and Biswas 1973). However, such methods do not adequately take into account political effects or influences that might be thought of as ethical or psychological. A very well known example of how cost-benefit analysis in the environmental-economics field can fail is the Report of the Commission on the Third London Airport (HMSO 1971). This was one of the most comprehensive cost-benefit studies ever carried out in the U.K., yet the Government rejected its recommendations within one month of receiving the submission, largely in response to political pressures from residents near the proposed site. Another example of the pure market-economy approach is found in Hore-Lacy (1976), where the value of timber production in the Jarrah forests of Western Australia,

\$20 per hectare per year, is weighed against the value of the bauxite under the forest, \$1,000,000 per hectare.

Approaches which leave out people's non-market attitudes towards the environment are open to criticism and it would seem appropriate for this project to take a scientific approach steering clear of value judgements. What a model such as SARUM can do is produce trade-off curves of the type shown in Figure 8. These show what other benefits have to be forgone in order to achieve a certain amount of stress reduction. The position on the curve at which society chooses to operate results from social and political actions. Some further insight can be gained by analysing revealed trade-offs inherent in past decisions. For example, in the case of the Third London Airport, it would be possible to deduce a lower bound on the revealed cost of disturbance to residents. Such figures could be one input to similar decision-making processes in the future. For example, one could say that if some airport is to be built then that decision might imply a valuation of disturbance to residents of, say, less than half that revealed by the residents near the 1971 proposed site. Although such results are deducible from observations of the real world and can thus be classed as scientific, it is not valid for them to preempt future decisions as people's attitudes to the environment can change greatly.

Another way of obtaining those curves is to close the feedback loops between the environment and the economy. This will probably be the main area of further development in the project. One way of doing this is to invoke the "polluter pays" principle in which certain pollution abatement measures are required of stress-producing activities. These measures have to be paid for, with a resulting increase in the costs of production. Eventually the final consumer would have to pay higher prices which would result in a lower standard of living. It will be very straightforward to introduce such requirements into the model, and again a trade-off curve would be produced relating stress reduction to the costs of control. It will be possible to apply the control costs to different parts of the economy, for example, the primary producers, the intermediate manufacturing industries or the final consumers. The effects on the structure of the economy can then be investigated. It is a moot point whether the increase in the production of pollution-control equipment balances the loss of production in the industries responsible for the stress. An economic model will be able to throw light on this question. Such changes in the cost structure of the economy could well affect trade, with Australia losing markets to countries which can produce goods more cheaply as a result of having more lax pollution standards. A model which deals comprehensively with trade, such as SARUM, is well suited for investigating problems of this type.

## 5. CONCLUSIONS

The way that an environmental capability can be incorporated in a global model has been described and some preliminary results presented. It has also been shown how a global model can be used to investigate the problems of one particular country by setting its economy in a world context. As has been seen, environmental stresses in Australia are very dependent on trade policy and the use of a global model has proved very valuable. For example, one can see that the large rise in fertilizer use in Australia is closely connected with rising food consumption in East and South East Asia. Global models are not a substitute for more specialised national models; they are complementary, dealing in more detail with the world context at the expense of detail in the home economy. It may indeed prove useful to take the trade flows from a global model and impose them exogenously on a national model. Without doubt, however, it will be advantageous for modellers to get together and discuss their different approaches. This will widen their horizons and help in their understanding of the world, which ultimately must be the aim of economic modelling.

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